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CHARACTERIZATION OF SEVERAL MATERIALS FOR PENETRATION EVALUATIO--ETC(U)

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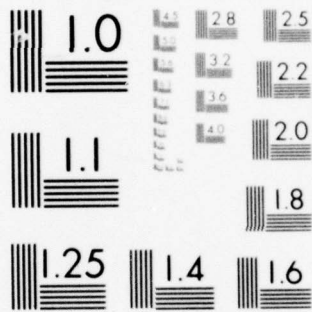
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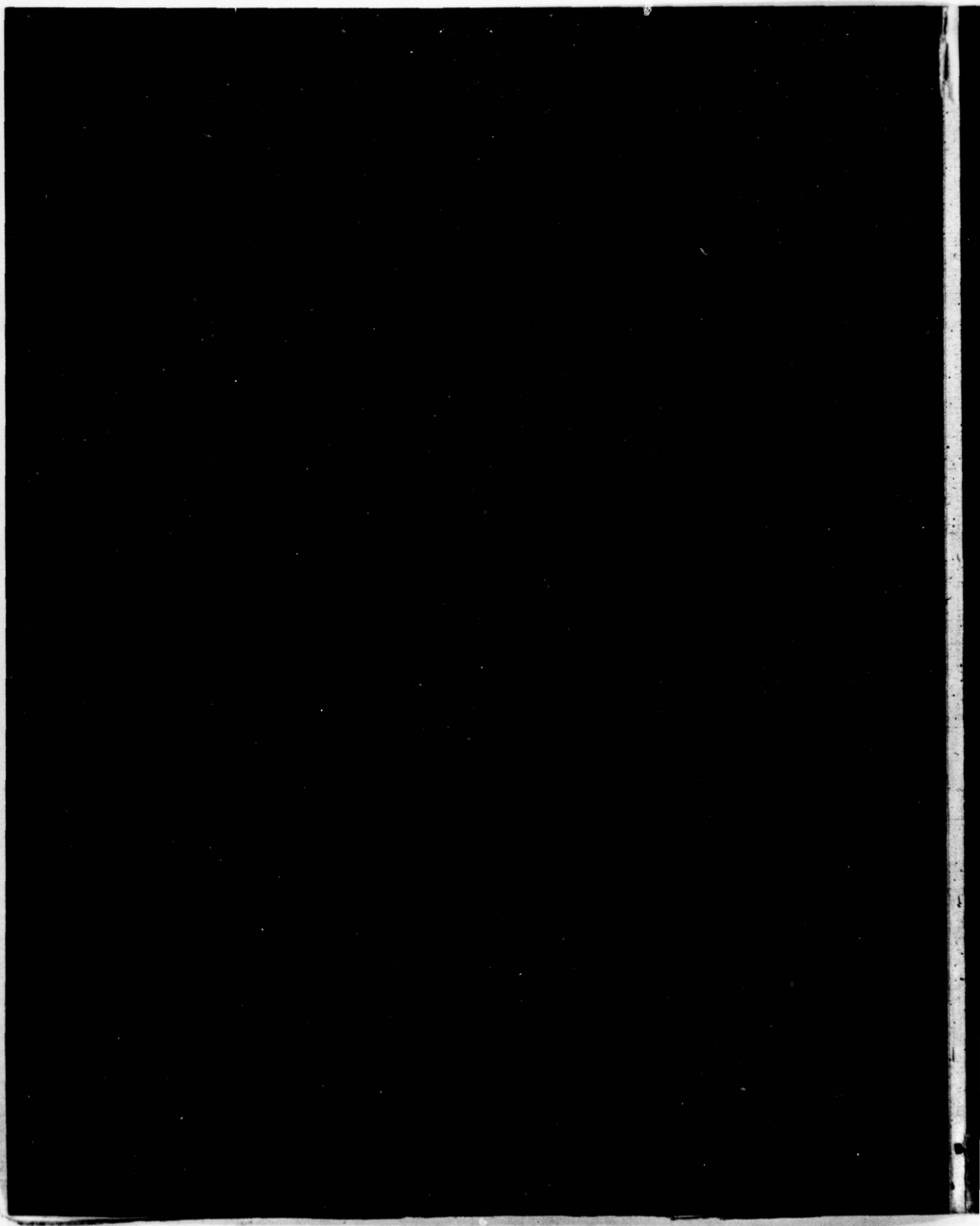
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INTRODUCTION

As part of the Defense Nuclear Agency's Earth Penetrator Program, material properties were measured for the evaluation of penetrator performance. The material properties of welded tuff and sandstone from two projectile penetration field sites, Mt. Helen and San Ysidu, were reported previously. More recent material characterization programs, for which the data is reported here, were conducted on a material comprising portions of the internal structure of the penetrator, MICA-50 potting compound, and on three man-made target materials: sand mix, gypsum and concrete.

The MICA-50 potting compound* was developed by Sandia Laboratories and is used to protect internal components of the penetrator during periods of high acceleration and deceleration. Detailed material property data makes it possible to define the individual loading histories of the components and thus provides the means for evaluation of the material as an encapsulating medium. Mechanical properties of this material were determined by unconfined compression, unconfined tension, triaxial compression and hydrostatic compression tests. Strain rate tests were also conducted to observe possible variation in moduli and yield stress with change of strain rate. The data obtained in this test program was previously reported in Terra Tek report TR 76-4, February 1976.

The first man-made target material evaluated was a sand mix developed by AVCO Corporation for reverse ballistic testing of instrumented half-scale penetrators. The material property testing conducted by the Waterways

* Preliminary results for the MICA-50 test program were reported previously in Terra Tek Report TR 76-4, entitled "Some Mechanical Properties of MICA-50 Potting Compound," by R. K. Dropek, S. W. Butters, and A. H. Jones.

Experiment Station (WES) was supplemented by Terra Tek, which performed tests to determine mechanical response at higher confining pressures. Triaxial compression tests were conducted at 1 and 4 kilobars confining pressure. Hydrostatic response was evaluated to 4 kilobars.

The second man-made target material evaluated was a gypsum of hydrostone and fiberglass, which has been developed as a standard target material for projectile penetration tests. Its homogenous and isotropic nature facilitates analysis of the effect of penetrator design changes on performance. The test program conducted on this material included: hydrostatic compression, unconfined compression, triaxial compression, uniaxial strain and triaxial extension tests.

A concrete fabricated by the University of New Mexico was the last man-made target material tested. Evaluation of the hydrostatic compression response and the determination of the failure envelope as a function of confining pressure were the primary material properties required. Additional properties tests were initially scheduled but the large sample aggregate limited the number of test samples.

MATERIAL DESCRIPTION AND PREPARATION

The materials tested contrasted significantly. MICA-50, a rigid encapsulating resin, was sand colored and had a density of 1.64 gm/cm^3 . The compound used in the AVCO testing contained sand, type 3 Portland cement and water (4.9%). Its small aggregate size (sand), made it appear homogeneous and the density of the material was 2.06 gm/cm^3 . The man-made gypsum of hydrostone and fiberglass had a density of 2.03 gm/cm^3 ; 1.89% was water. The fiberglass components were small, chopped strands distributed randomly in the mix. The University of New Mexico concrete penetration slab was poured from a mix per cubic yard of:

| | |
|------------------------|-----------|
| Coarse aggregate | 1674 lbs. |
| Fine aggregate | 1041 lbs. |
| Type 1 Portland cement | 738 lbs. |
| Water | 295 lbs. |

It was poured August 5, 1976 and had an air content of 5 percent with a slump of $2\frac{1}{2}$ inches. The concrete was sprayed with a resin based curing compound and was covered with a polyethylene sheet. The samples for testing were cured identically.

The specimens for all of the materials tested were cylindrical, except those for the MICA-50 tension test which were dog-bone shaped. The AVCO samples were stored at a temperature and humidity to coincide with handling by WES; no special storage instructions were received or implemented on the other specimens. Following coring and grinding each sample was carefully inspected for large surface and near surface air

voids which could result in a jacket puncture during pressurization. These voids were opened, cleaned and filled with a quick setting grout. When the surface voids were large and numerous, as with the University of New Mexico concrete, special procedures were warranted: the sample was wrapped with a dense, foam tape (with appropriate circular locations cut in the tape to allow strain measurement), jacketed with polyurethane and then the surface was sealed with a special solvent resistant silicone rubber compound. Ordinary sample jacketing was accomplished with several wraps of polyurethane which was sealed to steel end caps with lock wire.

Table I which lists the sample dimensions follows.

TABLE I
Sample Dimensions

| Material | Test Type | Dimensions |
|----------------------------------|---|---|
| MICA-50 ¹ | Compression | 0.75 ± 0.005" Dia. x 1.50 ± 0.02" Length (1.91 ± 0.013 cm) (3.81 ± 0.05 cm) |
| MICA-50 | Tension* | 0.30 ± 0.001" Dia. x 0.60 ± 0.01" Length (0.76 ± 0.003 cm) (1.52 ± 0.025 cm) |
| AVCO Sand Mix ¹ | Compression | 0.75 ± 0.005" Dia. x 1.50 ± 0.02" Length (1.91 ± 0.013 cm) (3.81 ± 0.05 cm) |
| Gypsum ¹ | Compression | 0.75 ± 0.005" Dia. x 1.50 ± 0.02" Length (1.91 ± 0.013 cm) (3.81 ± 0.05 cm) |
| New Mexico Concrete ² | Compression $\sigma_3 \leq 0.345$ kb | 6.0 ± 0.01" Dia. x 10.0 ± 0.005" Length (15.24 ± 0.03 cm) (25.4 ± 0.013 cm) |
| New Mexico Concrete ² | Compression $\sigma_3 > 0.345$ kb | 4.0 ± 0.01" Dia. x 8.0 ± 0.005" Length (10.16 ± 0.03 cm) (20.32 ± 0.01 cm) |

* Gage length dimensions given, samples were dog-bone shaped.

1. Sample ends ground parallel to within 0.0005 in.

2. Sample ends ground parallel to 0.003 in. or better.

TEST RESULTS

Each sample was placed in series with a strain gauged load cell within the loading frame to provide axial stress measurement during unconfined tests and stress difference during confined tests. The accuracy of the load cell was within 10 bars. The confining pressure, when present, was monitored by a manganin wire coil placed within the pressure cell and was accurate to within 10 bars.

Axial and transverse strains were measured with a strain gauged cantilever system. Strain measurement was accurate to 0.05% axial strain and 0.04% lateral strain. During the tension tests in the MICA-50 test program, strain gauges were bonded directly to the test samples.

With the exception of the MICA-50 test program, all stresses were applied quasi-statically at a constant rate of 1×10^{-4} in/in/sec. The strain rates used in the MICA-50 program are related in detail in the following section.

MICA-50 Test Program

The mechanical properties needed to document the material behavior of the MICA-50 compound are Young's modulus (E), Poisson's ratio (ν), bulk modulus (K), and yield stress (σ_y). These mechanical properties were obtained via unconfined compression and tension tests, triaxial compression tests, and hydrostatic compression tests. Strain rate tests were also conducted to observe possible changes in moduli and yield stress with variations in strain rate. Figure 1 shows the manner in which these E , ν , and σ_y are defined in this test program. The test results are summarized in Table II.

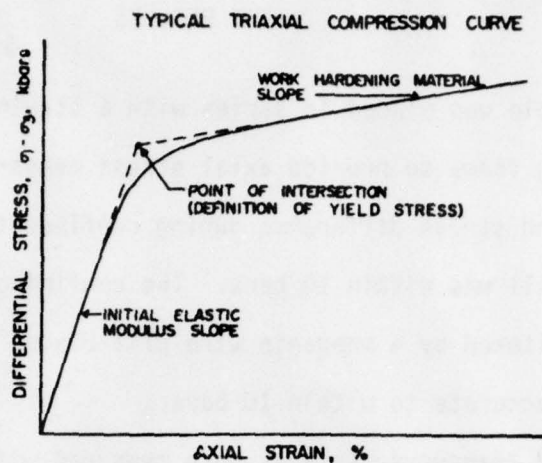


Figure 1. Definition of yield stress and Young's modulus.

TABLE II
MICA-50 Potting Compound Test Results

| TEST TYPE ($\sigma_3 = \sigma_2$) | STRAIN RATE in/in/sec | YOUNG'S MODULUS (E), Kb, ± 4 Kb | POISSON'S RATIO ν , $\pm .03$ | YIELD STRESS Kb | % AXIAL STRAIN at yield stress | BULK MODULUS (K), Kb, ± 4 Kb |
|--|--------------------------|--|--------------------------------------|--------------------|-----------------------------------|-------------------------------------|
| Tension ($\sigma_3 = 0$ Kb) | 10^{-2} | 82 | .33 | 0.54* | --- | -- |
| Triaxial Compression ($\sigma_3 = 0$ Kb) | 2 | 66 | --- | 1.43 | 2.2 | -- |
| Triaxial Compression ($\sigma_3 = 0$ Kb) | 10^{-1} | 66 | --- | 1.17 | 2.0 | -- |
| Triaxial Compression ($\sigma_3 = 0$ Kb) | 10^{-2} | 64 | .37 | 1.08 | 1.7 | -- |
| Triaxial Compression ($\sigma_3 = 0$ Kb) | 10^{-4} | 64 | .37 | 0.92 | 1.5 | -- |
| Triaxial Compression ($\sigma_3 = .25$ Kb) | 10^{-2} | 64 | .33 | 1.12 | 1.7 | -- |
| Triaxial Compression ($\sigma_3 = 1.0$ Kb) | 10^{-2} | 64 | .33 | 1.21 | 2.0 | -- |
| Triaxial Compression ($\sigma_3 = 4.0$ Kb) | 10^{-2} | 65 | .37 | 1.35 | 2.1 | -- |
| Hydrostatic Compression | 6×10^{-4} | -- | --- | --- | --- | 93 |

* Tension test did not show a definite yield point, sample failed at a stress of 0.54 kilobars.

The result of the tension test is shown in Figure 2. The test indicates a Young's modulus of 82 kilobars and a Poisson's ratio of 0.33. The sample failed brittly at 0.53 kilobars axial stress. The strain rate for this testing was 10^{-4} in/in/sec.

Four unconfined compression tests were performed over the range of strain rates; 10^{-4} , 10^{-2} , 10^{-1} and 2 in/in/sec. Figure 3 delineates the stress-strain curves for the four tests. Young's modulus remained constant at 65 ± 1 kb with the increasing strain rate.

The data from Figure 3 clearly indicates viscoplastic behavior. Defining the yield point as the intersection of the average linear elastic line with the line representing the strain hardening, the yield stress increases initially as a linear function of the log strain rate. This function becomes non-linear at the higher strain rates with the yield stress increasing. The yield stress versus the log strain rate is plotted in Figure 4.

Figure 5 shows a cycled unconfined compression test illustrating the elastic-plastic behavior and hysteresis. This test is not included in Table II.

The results of the hydrostatic compression are shown in Figure 6. The bulk modulus appears constant at about 84 kilobars up to a confining pressure of about 3 kilobars where it begins to increase slightly. No hysteresis occurred during the unload phase of the test.

The effect of confining pressure on the potting compound may be observed from the four triaxial compression tests shown in Figure 7. Tests were run at confining pressures of 0, 0.25, 1.0 and 4.0 kilobars at a

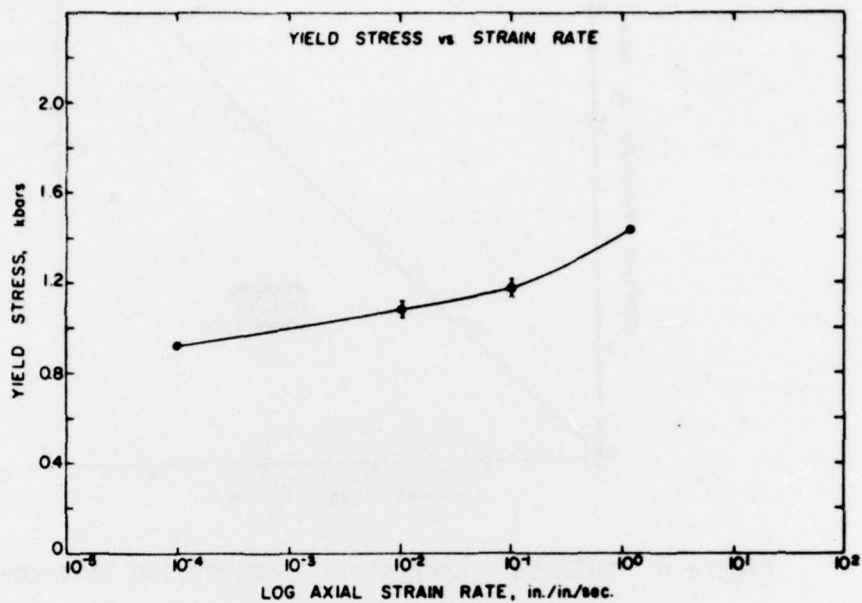


Figure 4. MICA-50 - Yield stress versus log strain rate of unconfined compression tests.

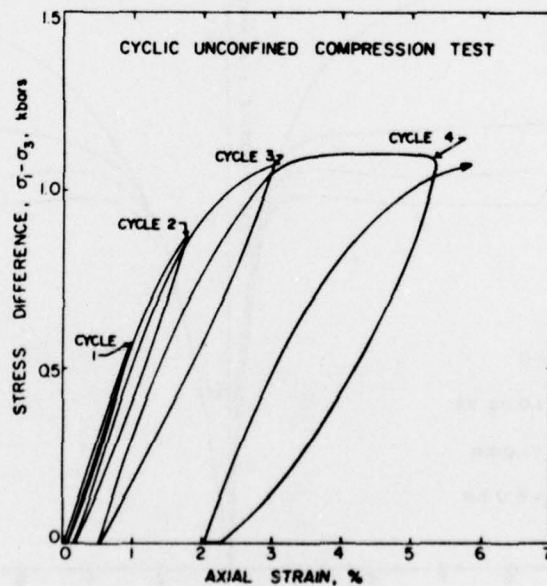


Figure 5. MICA-50 - Cycled unconfined compression test; strain rate of 10^{-2} in./in./sec.

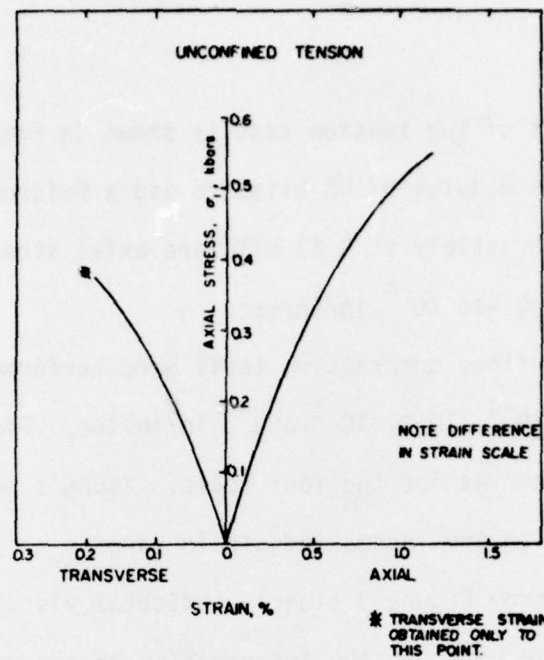


Figure 2. MICA-50 - Tension test results.

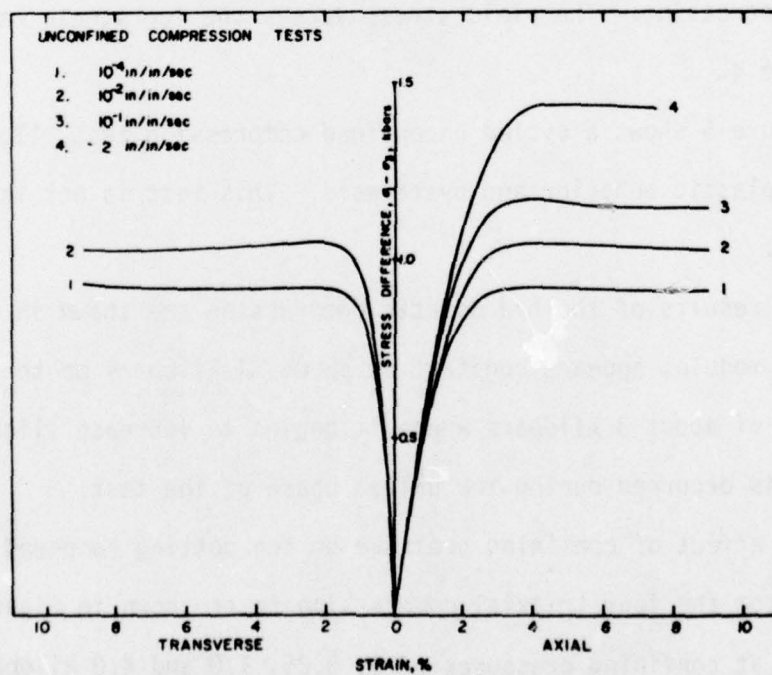


Figure 3. MICA-50 - Unconfined compression test results.

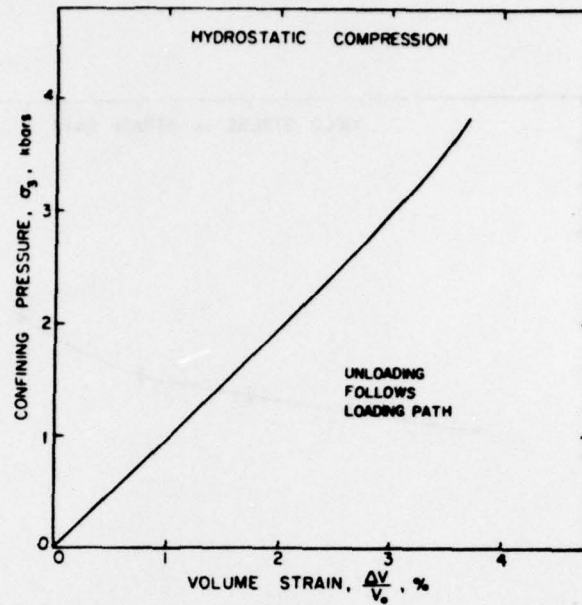


Figure 6. MICA-50 - Hydrostatic compression test results.

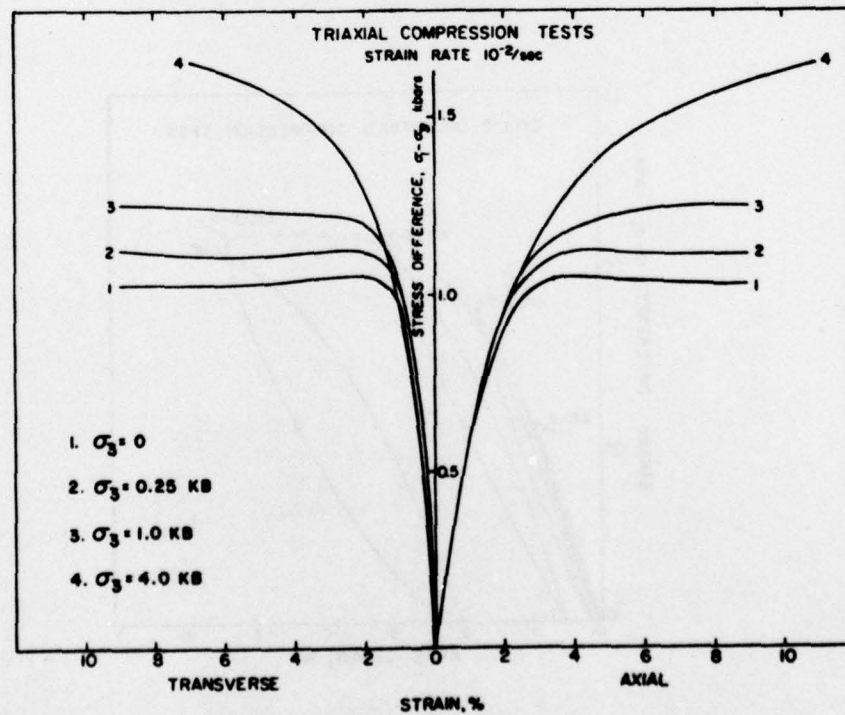


Figure 7. MICA-50 - Triaxial compression test results.

strain rate of 10^{-2} in/in/sec. The results of the four tests show a Young's modulus of approximately 65 kilobars and Poisson's ratios from 0.33 to 0.37. The yield stress increased from 1.08 kilobars to 1.55 kilobars as the confining pressures increased from 0 to 4 kilobars, as shown in Figure 8. Figure 9 is a photograph showing specimens which were tested at 0.25, 1 and 4 kilobars confining pressure.

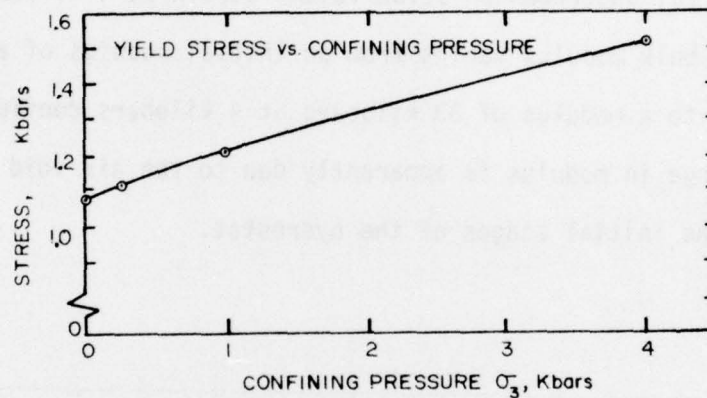


Figure 8. MICA-50 - Failure envelope.

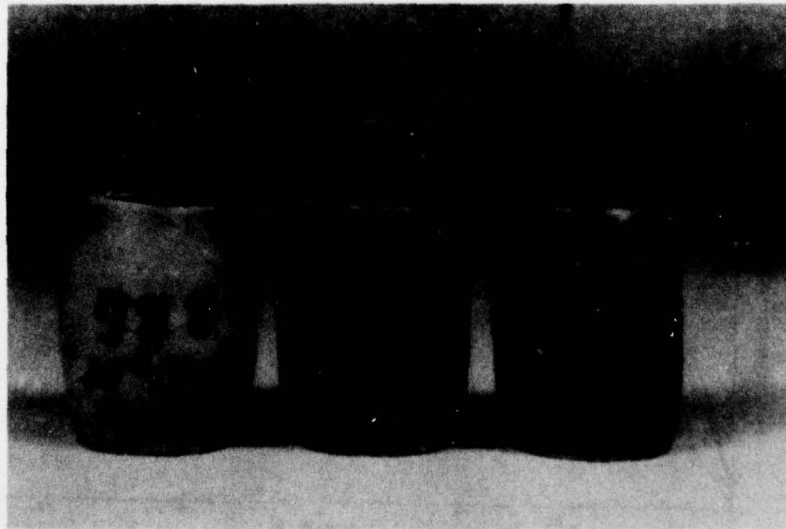


Figure 9. MICA-50 post-test triaxial compression samples; confining pressures of 0.25, 1.0 and 4.0 kilobars.

AVCO Sand Mix Test Program

Hydrostatic compression and triaxial compression tests were conducted on the AVCO sand mix. The hydrostatic response of the sand mix to 4 kilobars confining pressure is shown in Figure 10. Sample strain is plotted versus the confining pressure (σ_3). From the individual strain components shown in Figure 10, it is apparent that the material behavior is isotropic. The material undergoes an 11.5% volume strain at 4 kilobars.

The bulk modulus varies from an initial modulus of approximately 170 kilobars to a modulus of 33 kilobars at 4 kilobars confining pressure. This change in modulus is apparently due to the air void crush up occurring during the initial stages of the hydrostat.

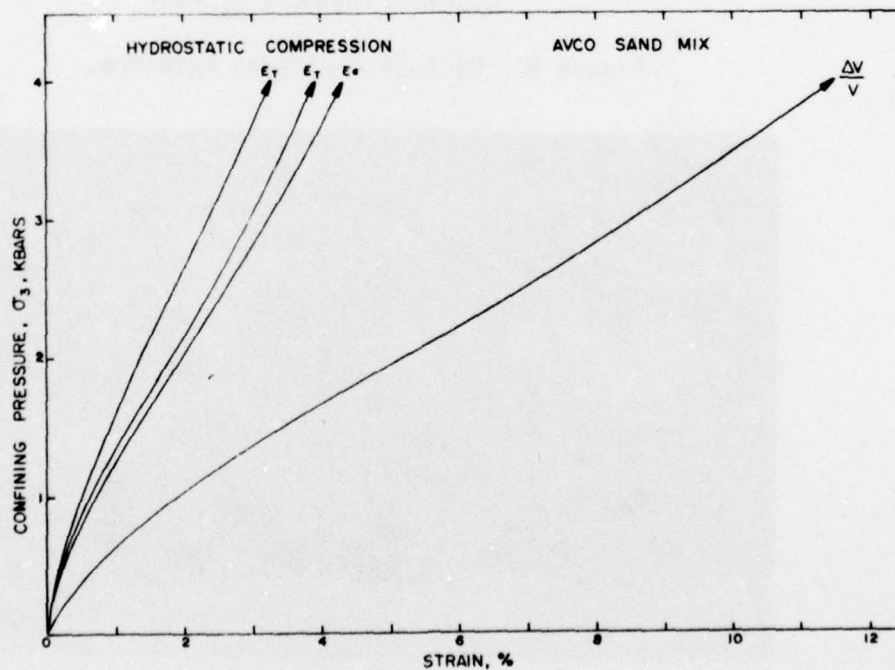


Figure 10. AVCO Sand Mix - Hydrostatic compression.

Figure 11 shows the results of the triaxial compression tests conducted. Stress difference is plotted versus the axial and transverse strains. At these confining pressures, the material behaves quite ductily. The material shows an elastic-plastic behavior and does not demonstrate a linear elastic region at either confining pressure.

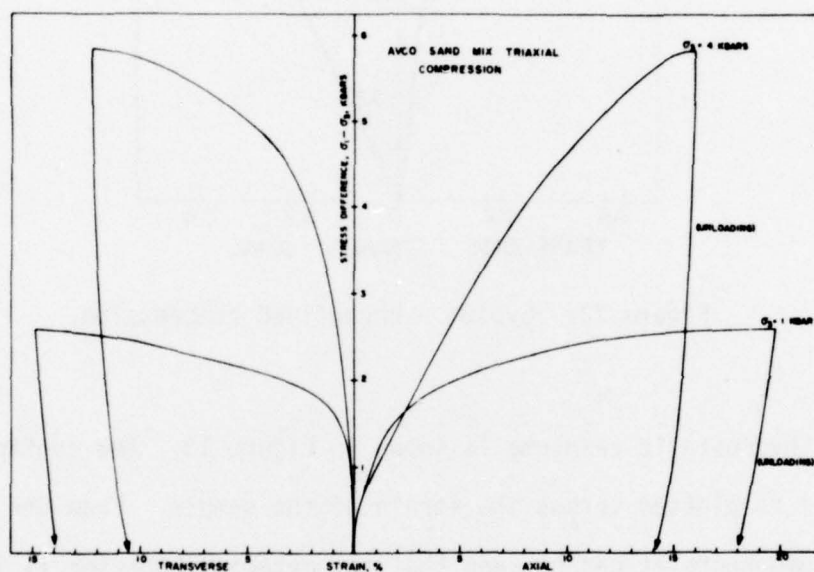


Figure 11. AVCO Sand Mix - Triaxial compression.

Gypsum Test Program

The test program conducted to define the mechanical response of the gypsum materials included: unconfined compression, hydrostatic compression, triaxial compression, uniaxial strain and triaxial extension.

The result of the unconfined compression test is shown in Figure 12. The material response was linear with a Young's modulus of 200 kilobars. The sample failed brittlely at 0.6 kilobars axial stress.

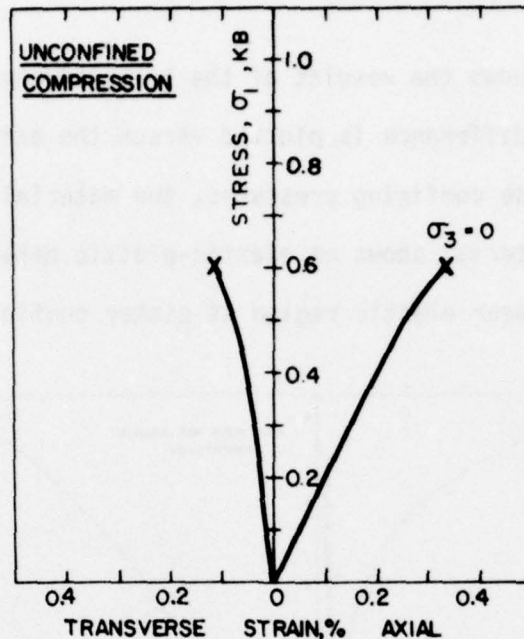


Figure 12. Gypsum - Unconfined compression.

The hydrostatic response is shown in Figure 13. The confining pressure (σ_3) is plotted versus the strain of the sample. From the individual strain components it can be seen that the material behavior is isotropic. The volume change at 4 kilobars confining pressure is approximately 10%. The initial bulk modulus is approximately 108 kilobars.

The results of the triaxial compression testing are shown in Figure 14. Stress difference is plotted versus the axial and transverse strains. The 0.5 kilobar confining pressure test shows an initially linear region with a pronounced transition in slope occurring at approximately 1 kilobar stress difference. The sample was strained to approximately 19% axial strain but did not fail. The triaxial test samples tested at 2.0 kilobars and higher did not demonstrate this initial linear region. The material exhibited permanent deformation from the initial application of the shearing

stress. The test was stopped at a stress difference of 2.65 kilobars and an axial strain of 10%. All triaxial compression tests showed extensive permanent deformation. Numerous lateral cracks were present in the post-test material.

Additional triaxial tests were conducted using partially instrumented samples (special high strain axial cantilevers only) to define stress differences at failure. Maximum load criterion was used to define failure. Figure 15 summarizes the data for gypsum; these samples reached axial strain in excess of 25%.

Uniaxial strain test results are contained in Figures 16a and 16b. Mean stress is plotted versus axial deformation in Figure 16a; stress difference is plotted versus confining pressure in Figure 16b. Very little recovery is noted during the unload portion of the strain path. Each sample showed extensive lateral fracturing upon post-test examination.

Figure 17 contains the results of the extension tests conducted on the hydrostone material. The axial stress difference (which is negative in an extension test) is plotted versus the transverse and axial strains. The sample confined at 0.2 kbars failed in tension while the 0.5 kbars sample failed at a compressive axial stress state. There was an increase in strain to failure with increase in confining pressure.

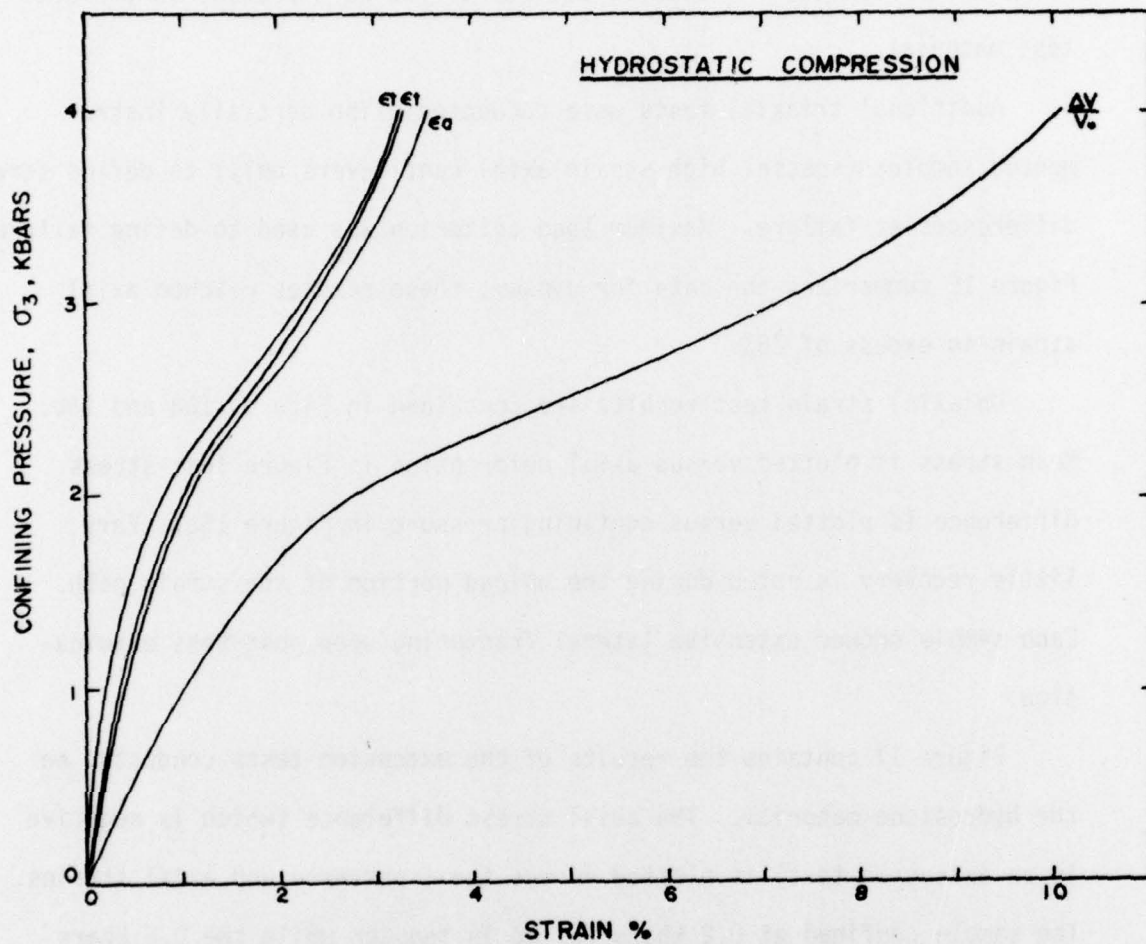


Figure 13. Gypsum - Hydrostatic response to 4 kilobars.

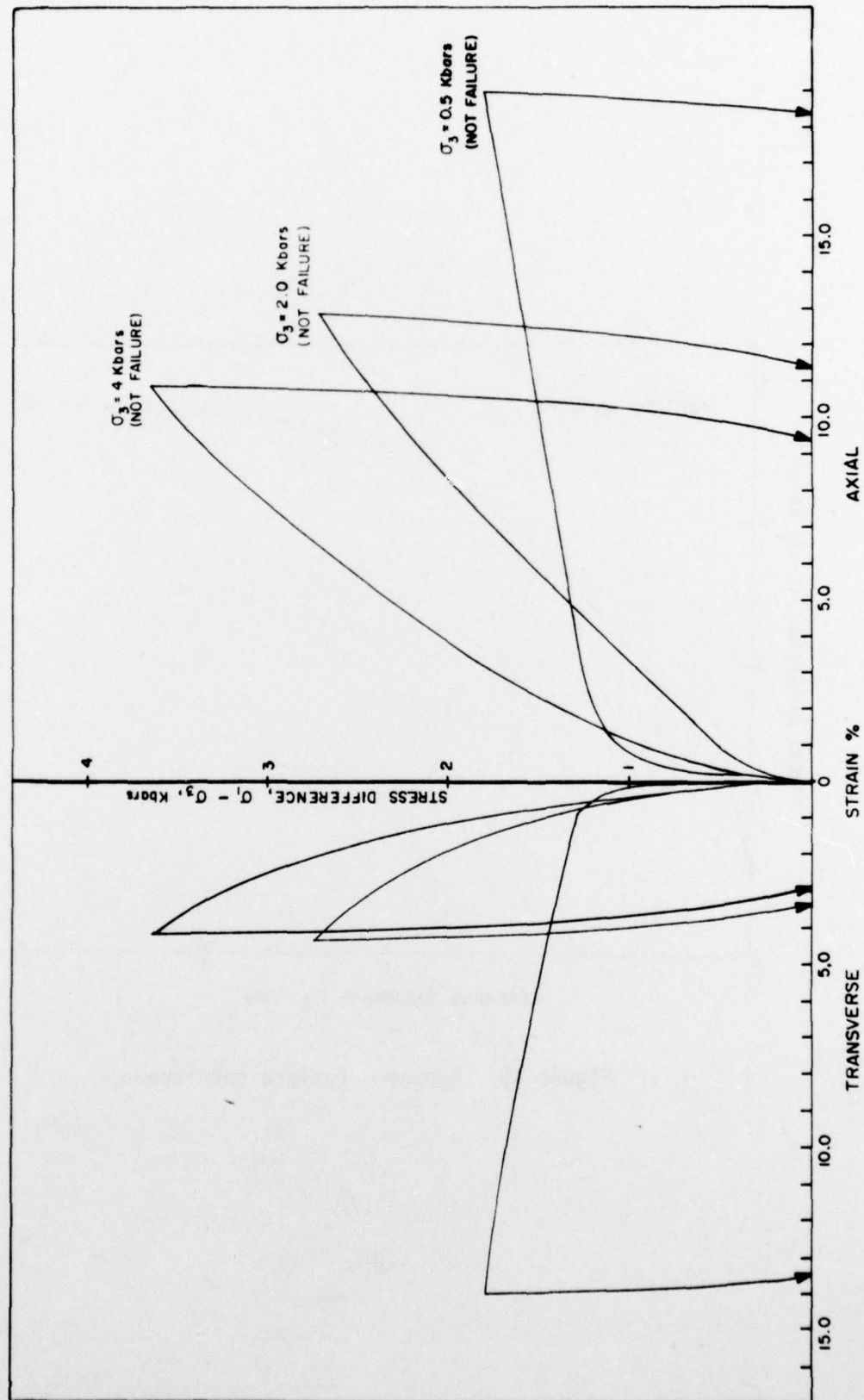


Figure 14. Gypsum - Triaxial compression.

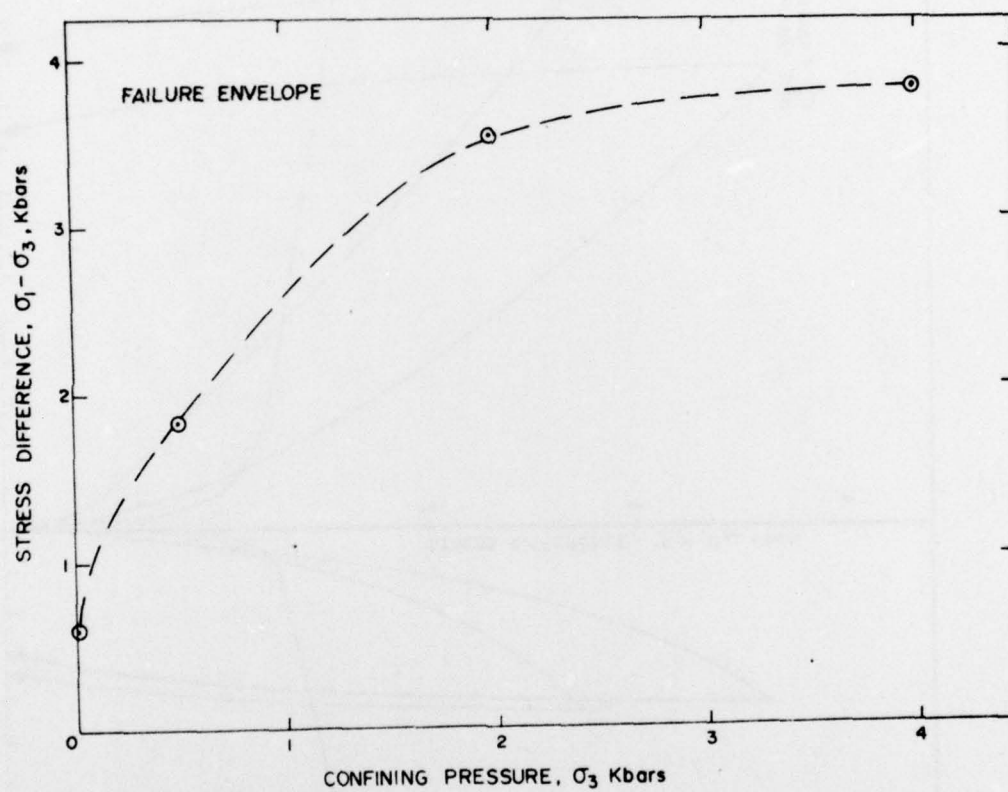


Figure 15. Gypsum - Failure envelope.

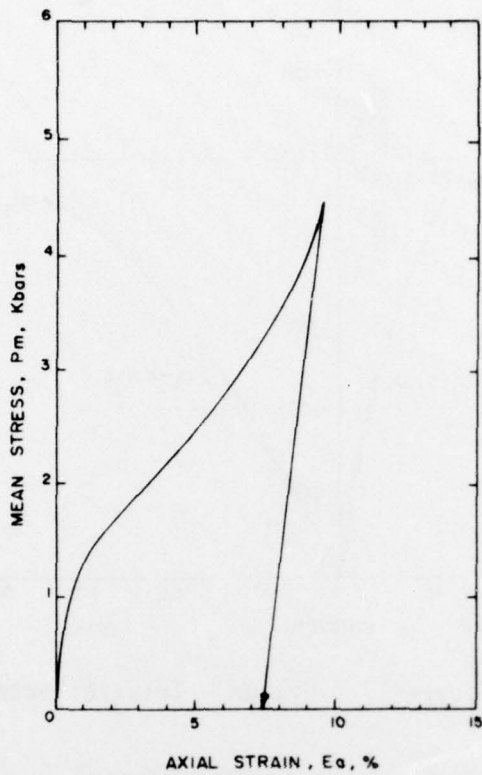


Figure 16a. Gypsum - Uniaxial strain test.

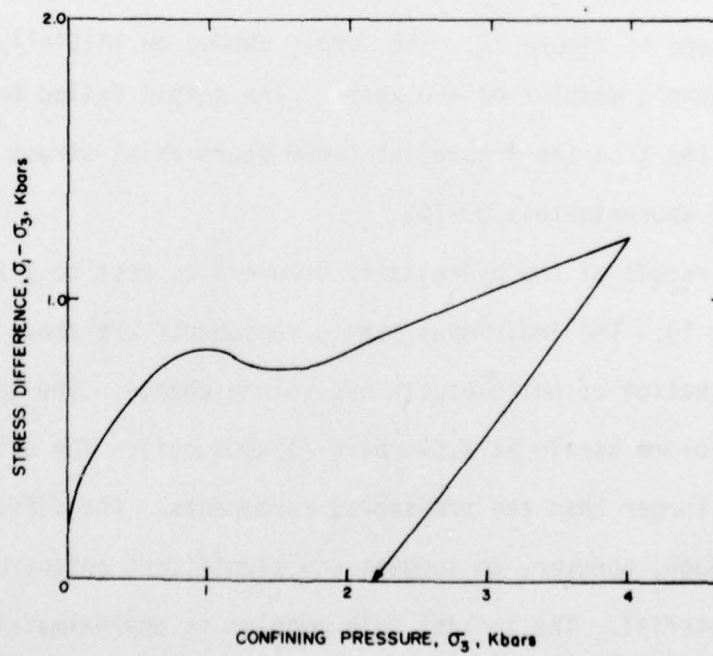


Figure 16b. Gypsum - Uniaxial strain test.

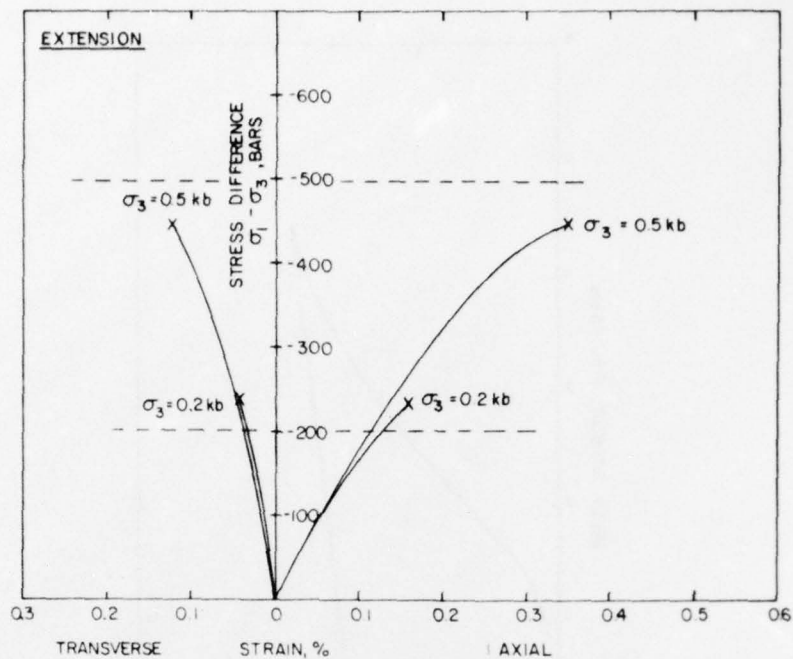


Figure 17. Gypsum - Triaxial extension.

University of New Mexico Concrete Test Program

Unconfined, hydrostatic, and triaxial compression tests were conducted on the University of Mexico concrete. The unconfined compression test results are included in Figure 18. The sample showed an initially linear response with a Young's modulus of 400 kbars. The sample failed brittly (as denoted by the X on the figure) at 0.650 kbars axial stress and at an axial strain of approximately 0.275%.

The result of the hydrostatic compression test to 1 kilobar is shown in Figure 19. The individual strain components are shown on the left, the combination of which equals the volume change. The sample demonstrates a 1.08% volume strain at 1.03 kbars (15,000 psi). The axial strain was slightly larger than the transverse components. The difference is not large enough, however, to suggest any significant anisotropic behavior of the material. The initial bulk modulus is approximately 109 kbars.

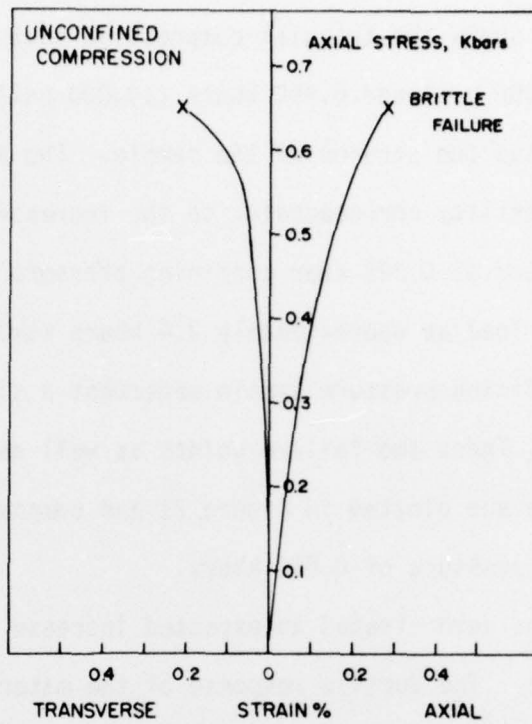


Figure 18. University of New Mexico Concrete - Unconfined compression.

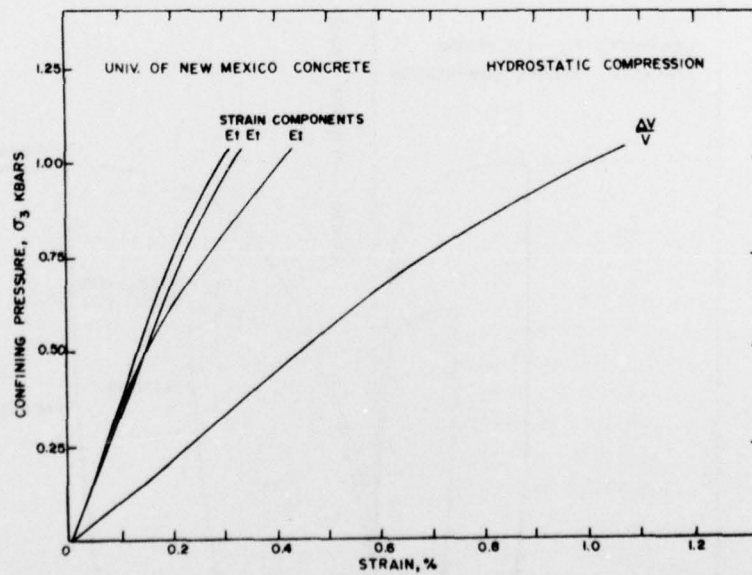


Figure 19. University of New Mexico Concrete - Hydrostatic compression.

Figure 20 shows the triaxial compressive test results conducted at 0.345 kbars (5000 psi) and 0.690 kbars (10,000 psi). The stress difference is plotted versus the strains of the sample. The samples demonstrate an increase in ductility corresponding to the increasing confining pressure. The sample tested at 0.345 kbar confining pressure began straining with no increase in load at approximately 2.4 kbars stress difference. The 0.690 kbar confining pressure sample underwent a similar ductile failure at 3.70 kbars. These two failure points as well as the failure of the unconfined sample are plotted in Figure 21 and compose a failure envelope to a confining pressure of 0.690 kbars.

The samples demonstrated an expected increase of strength with confining pressure. The ductile response of the material is best attributed to the collapse of the numerous pores produced by entrapped air. The unload portion of the triaxial compression curves shows extensive plastic deformation.

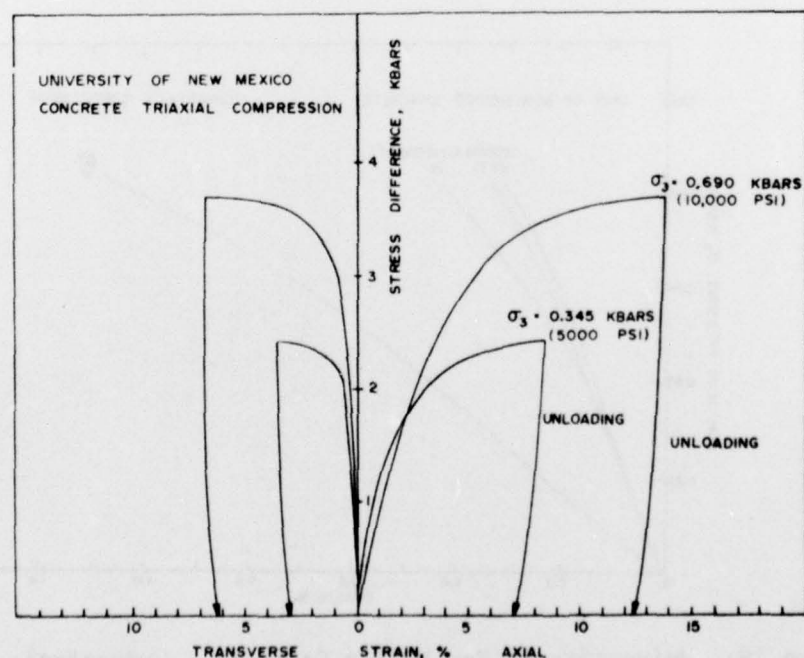


Figure 20. University of New Mexico Concrete - Triaxial compression results.

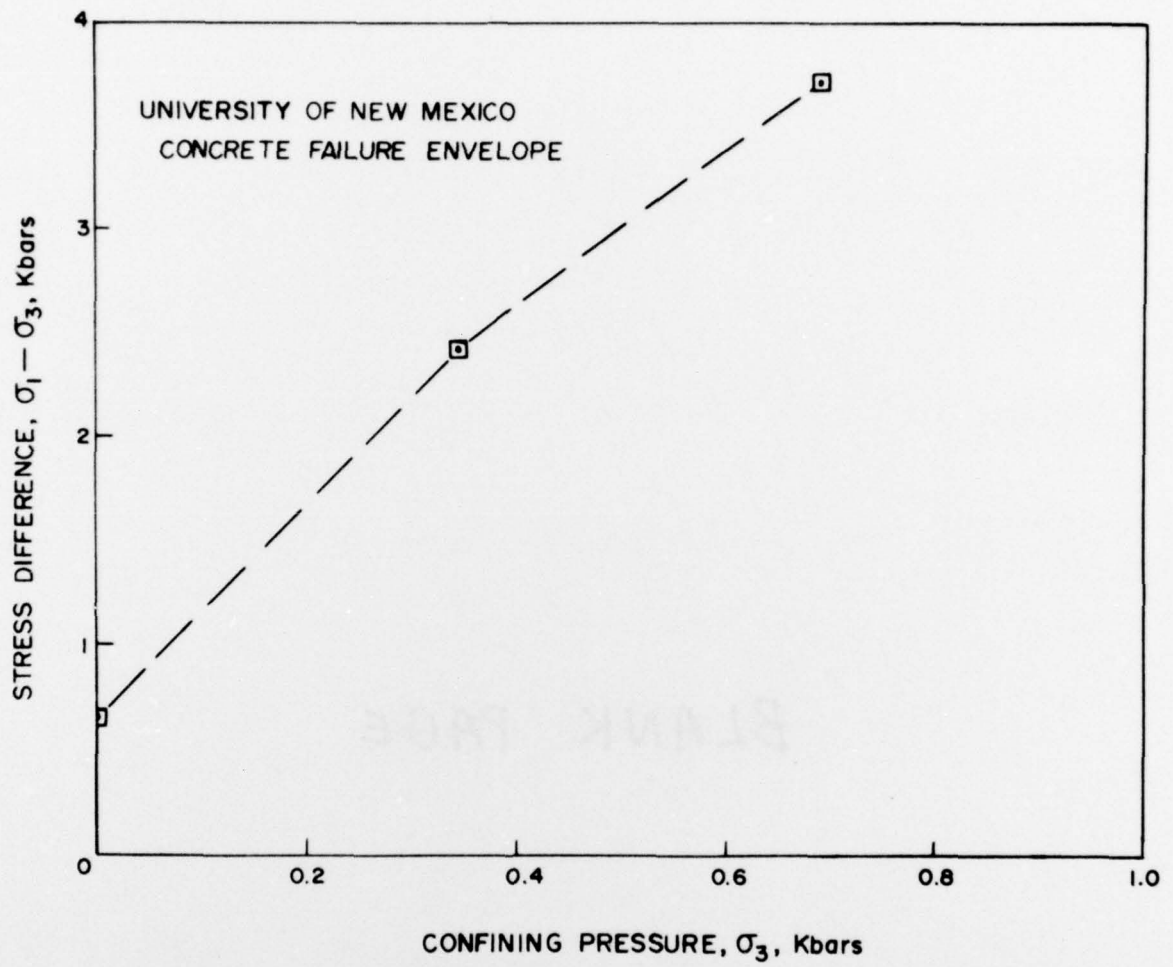


Figure 21. University of New Mexico Concrete - Failure envelope.

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